

PRACTICAL EXPERIENCES FROM A LOAD MEASUREMENT CAMPAIGN FOR THE ASSESSMENT OF THE REMAINING SERVICE LIFE OF WIND TURBINES

Michael Melsheimer**, Dipl.-Ing. René Kamieth*, Prof. Dr.-Ing. Robert Liebich*;
Dr.-Ing. Christoph Heilmann**, Dipl.-Ing. Anke Grunwald**

*Technische Universität Berlin, Fachgebiet Konstruktion und Produktzuverlässigkeit, Institut für Konstruktion, Mikro- und Medizintechnik, Sekr. H66, Straße des 17. Juni 135, 10623 Berlin, Germany, Tel.: +49-(0)30-31423603, Fax: +49-(0)30-31426131, rene.kamieth@campus.tu-berlin.de;

**BerlinWind GmbH, Bundesallee 67, 12167 Berlin, Tel.: +49-(0)30-6883337-40, info@berlinwind.com

Summary

After a rapid growth in wind turbine numbers beginning in 1990 in Germany, several thousand turbines now reach the end of their 20 year design life. Operators often wish to extend the service life of their turbines, but technical and legal guidelines do not yet specify a clear path. Current methods for the assessment of the remaining service life include inspection, renewed calculation or a combination of both. However, with these methods, damages may be detected too late, or fatigue is misjudged, as the endured loads are not realistically considered.

The presented research project proposes a new approach to enhance the above mentioned methods: The loads on the specific turbine are measured with an efficient load measurement campaign for several weeks to verify its structural behaviour and loading. The results are combined with additional information of the turbine's lifetime for a holistic assessment of the actual lifetime consumption and thus the remaining service life.

A load measurement campaign has been set up in June 2014 in order to test this method, gain practical experience and perform sensitivity studies. Operational data is available for almost the entire lifetime of now 15 years. Practical challenges include the investigation of classing parameters, as the ones proposed in the appropriate guidelines often cannot be produced from the available operational data. Evaluations of the data so far have confirmed a highly individual dynamic behaviour, even for turbines of the same or similar type at the same site. The measurement campaign will be continued to gain additional data and experience.

1. Introduction

Currently, several thousand wind turbines (WT) in Germany reach the end of their 20-year design life. For the desired period of continued operation, the German Building Authority requires an individual proof of the turbine's structural integrity and operational safety based on the DIBt guideline (October 2012) [1]. In contrast to DNV-GL [3], the combination of a renewed calculation and a detailed inspection is prescribed as applicable approach.

However, these methods may underestimate the individual turbine's actually endured loads since its structural response depends e.g. on the individual turbine settings, like intolerable blade angle deviation, resonance issues and/or pre-damage. With a renewed calculation based on site wind data and the ideal turbine model, etc., these parameters are neglected. On the other hand, the inspection detects damages only when it is quite late for preventive measures, since the increased loads have been acting already for a long time at the spot in question. The presented research project proposes a new approach to enhance the above mentioned methods: The loads on the specific turbine are measured with an efficient load measurement campaign for several weeks to verify its structural behaviour and loading. The results are combined with additional information of the turbine's lifetime for a holistic assessment of the actual lifetime consumption and thus the remaining service life.

A load measurement campaign has been set up in June 2014 in order to test the method, gain practical experience and perform sensitivity studies. Opera-

tional data is available for almost the entire lifetime of now 15 years.

2. Approach

2.1 Description of the proposed method

The vibrations of wind turbines are complicated and have very individual causes. They are dependent on the site-specific stochastic wind loads, on rotor imbalances and wear (erosion), and the interaction of the external forces with the internal structure of drive train, tower and foundation. In the design based on standards [3, 5] and guidelines [1, 2], WT types are extensively investigated by simulation of operational and extreme load cases for the targeted wind class. The load assumptions are validated by load measurements according to IEC 61400-13 [2]. For the building approval, it is verified whether the site's wind conditions are below the wind class limits for the turbine type, else additional load assessments are necessary. After years of operation, the turbine has endured some fatigue and will most likely behave differently compared to the time of commissioning. A measurement of the current loading situation is then a reliable way of determining a turbine's actual dynamic behaviour and hence applied in the approach presented here.

The campaign is set up for efficiency, meaning reduced duration and number of sensors compared to an extensive prototype measurement according to [2]. A goal is to be able to realistically assess the fatigue condition of the turbine's supporting structure in an economical manner, even and especially

for individual and smaller turbines, affected by the end of their design life right now and where there is no or limited WT type design data for simulation available apart from a type approval with some design load spectra.

2.2 Measurement system

The main requirements for the measurement system are compactness for an economical application while maintaining a sufficient measurement accuracy for modelling the dynamic behaviour and the fatigue loading of the wind turbine.

The measurement system for the current measurement campaign consists of 17 sensors (figure 1):

- 5 strain gauges, for strain and stress in the tower top and base,
- 5 acceleration sensors, for lateral, axial and torsional accelerations i.e. forces in the nacelle and the tower top,
- 3 turbine data sensors (azimuth position, electrical power, rotational speed),
- 4 meteorological sensors (anemometer and wind vane on top of the nacelle, ambient air pressure and temperature below the nacelle).

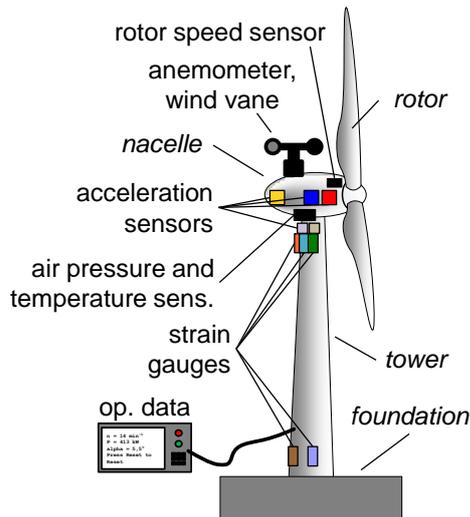


Figure 1: Measurement system installed at a wind turbine

Additionally, operational data of the turbine is measured simultaneously (electrical power, rotational speed, wind speed and azimuth position). With this data, a reconstruction of the endured loads before the beginning of the measurement campaign is possible. As there are no permanent load records, the turbine's 10 min operational data is used for correlation with the data of the measurement campaign.

The measurement is controlled by a robust mini PC (operational from -20°C ... $+70^{\circ}\text{C}$, with no moving parts), which can be remotely controlled by LAN or UMTS. The data acquisition is performed by a special measurement LabVIEW-based software.

2.3 Reconstruction of endured loads

The goal of the measurement campaign is to determine the dynamic behaviour of the aged turbine, and then to reconstruct the endured loads of its

service life. For this time period, there is at best operational data as 10 min mean values available, sometimes even with additional minimum and maximum values. During the short-time measurement campaign, the operational data is recorded simultaneously with the load data. Classing according to IEC 61400-13 [2] reduces the data to a more manageable amount and allows a correlation between operational and load data.

The IEC proposes a two-parameter classing with mean wind speed v_m and turbulence intensity I ($I = \sigma_v / v_m$), which depends on the standard deviation σ_v and the mean wind speed v_m . However, there is typically no turbulence intensity in the operational data. The search for a reliable substitute value is one of the challenges in the ongoing research.

3. Current experiences

3.1 Examined turbine

A load measurement runs successfully since June 2014 at a 15 years old 600 kW Pitch turbine with a 65 m steel tower, located in a small wind farm in flat terrain. The other three turbines are at a distance of 6, 8 and 10 times the rotor diameter, figure 2. The GL [3] and DIBt [1] guidelines require the consideration of the wake when turbines are closer than $10 D$, which is the case for two turbines here.

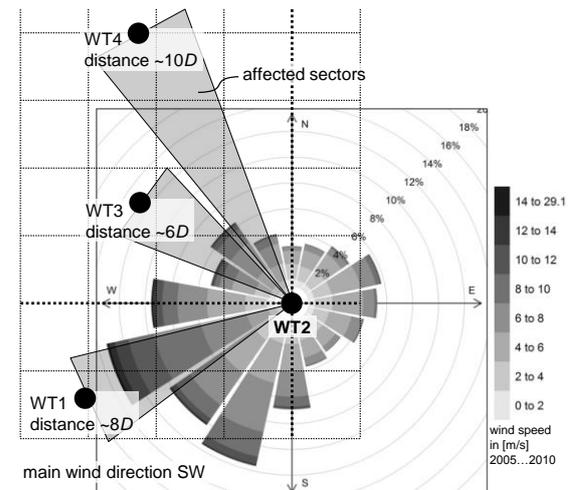


Figure 2: Sectoral wind speed distribution between 2005 and 2010 for the examined turbine "WT2", and wind sectors affected by the neighbouring turbines (note the location of WT1 in the sector of main wind direction for WT2)

The data basis for the examined turbine is very good, operational data is continuously available from 2005 on with a 98% availability. The data include 10 min mean values, minima and maxima of wind speed, rotor speed and electrical power, as well as azimuth position and error status (times and codes). The turbine is in good shape with regular service inspections. However, significant differences in the power and rotor speed curve are observed compared to the neighbouring turbine of the nearly similar type and age, figure 3, discussed later.

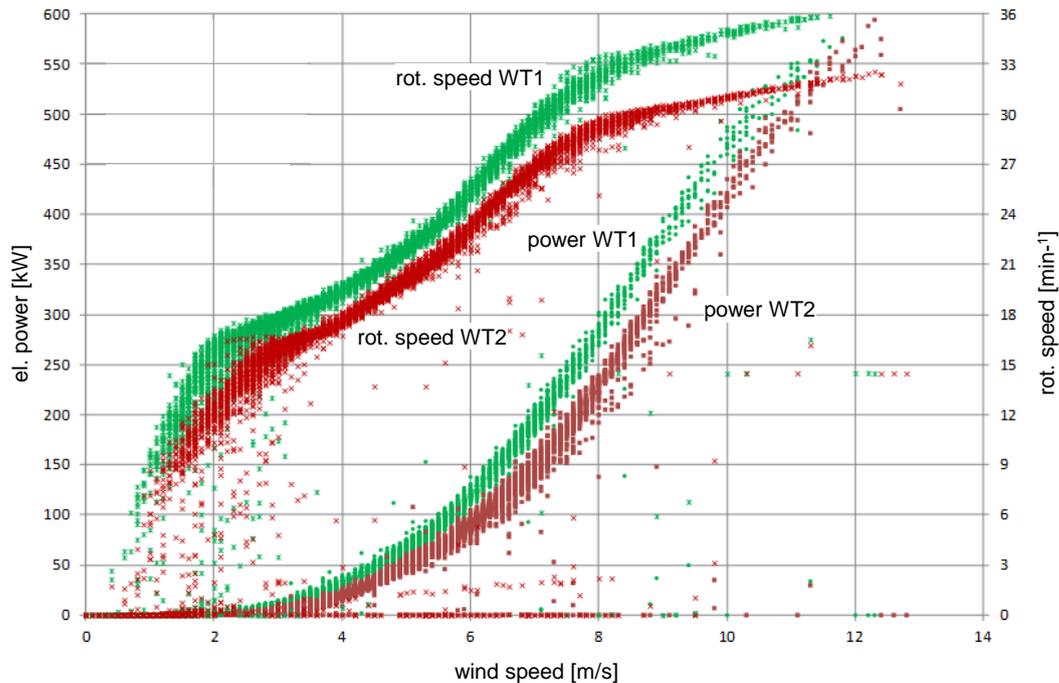


Figure 3: Electrical power and rotor speed versus mean wind speed, simultaneous 10 min operational data of the examined wind turbine “WT2” and the almost identical turbine “WT1”

As research on the method is still in progress, the measurement campaign is run for at least a year. The data then allows comparing results for different measurement periods and durations in order to determine the reasonable minimum measurement duration.

3.2 Alternative classing parameters

A basic problem for the classing of the operational data is the lack of the turbulence intensity I or values that allow a direct calculation of I . The IEC guideline [2] demands this value as a classing parameter, hence, a substitute turbulence intensity value I_{sub} is needed. In order to avoid additional costs for simulated wind data for the site, it is investigated whether it is possible to derive I_{sub} from the turbine’s operational data at hand. Available operational data consists of mean, minimum and maximum values, measured on top of the nacelle, where the rotor wake influences the measurement.

An approach investigated uses an established formula for the calculation of the extreme gust V_{e50} , from mean wind speed V_{m50} and turbulence intensity I [1, 3, 4]:

$$V_{e50} = V_{m50} \cdot (1 + B \cdot I)$$

B is the gust factor, given as $B = 2.8$ in the literature for various heights [4]. Rearranging this formula while substituting V_{e50} and V_{m50} for the available mean and max. values $v_{max,10}$ and $v_{m,10}$ gives

$$I_{sub} = (v_{max,10} / v_{m,10} - 1) / B.$$

However, evaluations of various measurement data have shown that the common value $B = 2.8$ can only be reproduced when averaging wind speed bins over longer periods. For 10 min time series, the variance of $v_{max,10}$ is too large for a reasonable use of a constant or site-calibrated value for B .

Although many combinations of minimum, maximum and mean values from wind speed, power and rotor speed have been investigated, no satisfying single parameter has been identified yet.

3.3 Transferability to other turbines

During type certification [3, 5] it is assumed that the prototype measurement results may be generalized for the turbines of the same type. Hence, to reduce measurement effort, it needs to be discussed whether, it may be possible to use the load measurement data obtained at one aged turbine in order to assess the endured loads and the residual service life of another turbine of the same turbine type e.g. in the same wind farm.

At the site of the examined 600 kW turbine “WT2”, the neighbouring “WT1”, figure 2, was erected at the same time but has slightly different blades and in addition other aerodynamic elements installed. Furthermore, the number and frequency of the wind sectors disturbed by fatigue-relevant wake effects differs. Figure 4 shows that for WT1 the load spectra for undisturbed and disturbed wind sectors differ significantly.

An analysis of the operational data of WT2 and WT1 () shows significant differences in the power and rotor speed curves, figure 3. At the same wind speed in partial load, WT1 has a higher power production and rotor speed than WT2. As the centrifugal mass forces and aerodynamic forces of the rotor increase by the squared rotor speed, a corresponding increase in the general load levels seems possible for WT1. Furthermore, the frequency of time periods where WT1 and WT 2 operate at their tower’s resonance frequency, which is within the operational range, will differ. However, it is also possible that e.g. the wake-related increased loading on WT2

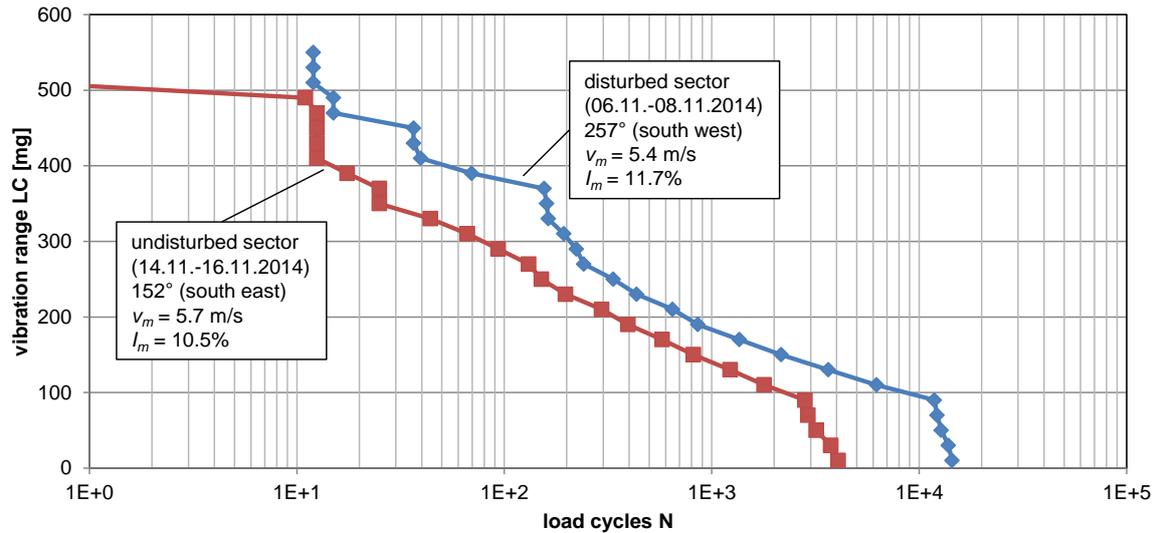


Figure 4: Exemplary load spectra (lateral acceleration “LC”) for two day’s periods with approx. the same mean wind speed v_m , blue/rhombi: disturbed wind sector with wake effect and red/squares: undisturbed wind sector where the loads are noticeably lower

led the OEM to a reduction of its power curve and rotor speed curve, with the aim of reducing the load level. Therefore, it seems that only further measurements at similar turbines will show whether or not it is possible to use load spectra measured at one turbine to assess the endured loads and remaining service life of another similar turbine. At present, it seems to be necessary to perform individual load measurements.

4. Conclusion

With the presented project, a method for the realistic assessment of the remaining service life of wind turbine structures is developed and tested. The approach can be seen as complementary to the methods, proposed by the guidelines [1, 6]. Its main innovation is the goal of a reliable, yet still economical assessment based on actual, individual load measurement results. One challenge lies in the correlation of the high resolution load measurement data with the 10 min mean operational data which do not contain directly the turbulence intensity, which is the important second classing parameter. Therefore, a reliable substitute value needs to be derived. Further parameters influencing the classing and thus the statistical distribution of the loads have to be identified, with the goal to assure the acquisition of a representative amount of relevant data that allows a realistic assessment of the remaining service life.

5. Acknowledgements

The doctoral stipend at TU Berlin is kindly granted by the Reiner Lemoine Stiftung and supported by BerlinWind GmbH. The measured wind turbine is kindly provided by Terrawatt GmbH.

6. References

- [1] Deutsches Institut für Bautechnik (DIBt): *Richtlinie für Windenergieanlagen* (Guideline for Wind Turbines), 2012
- [2] International Electrotechnical Commission: *IEC 61400-13, Wind turbine generator systems – Part 13: Measurement of mechanical loads*, 2001
- [3] Germanischer Lloyd (GL): *Guideline for the Certification of Wind turbines*, 2010
- [4] R. Gasch, J. Twele: *Wind Power Plants*, Springer, Second Edition, 2011
- [5] International Electrotechnical Commission: *IEC 61400-1, Wind turbines, Part 1 1: Design requirements*, 2005
- [6] Germanischer Lloyd: *Guideline for the Continued Operation of Wind Turbines*, 2009